Appendix C:

Measurement Considerations for the mmWave Bands

Power Measurement Distance

Millimeter Wave antennas can produce patterns with a wide variety of far-field distances, where R, the far-field distance is conventionally taken as:[1]

$$R = \frac{2D^2}{\lambda} \quad \text{or......} \quad \left(\frac{R}{\lambda}\right) = 2\left(\frac{D}{\lambda}\right)^2$$

And: D= Height or diameter of antenna aperture
λ = wavelength

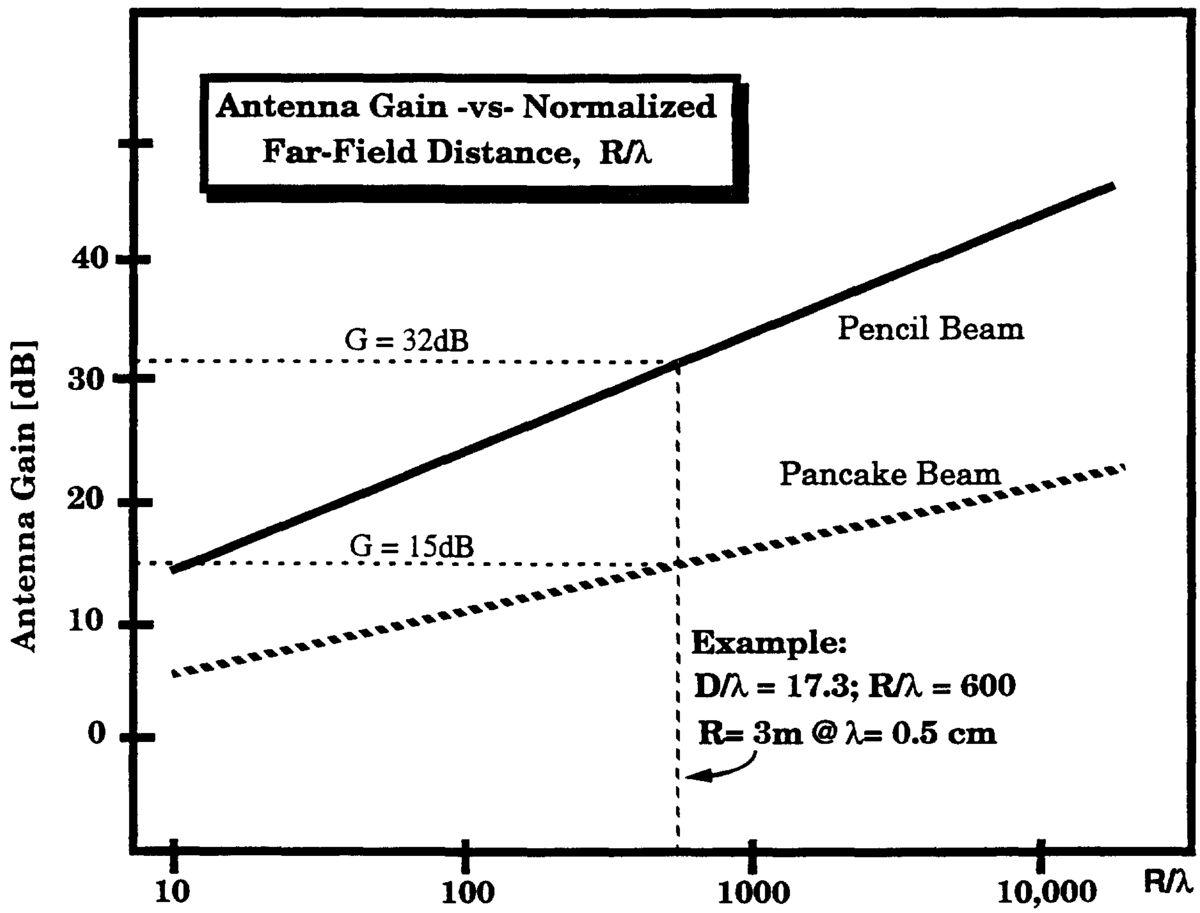
Similarly, antenna gains can be expressed in terms of D/λ:

$$Gpencil = 5.4\left(\frac{D}{\lambda}\right)^2 \qquad Gpancake = 1.9\left(\frac{D}{\lambda}\right)$$

For a typical "pencil" beam, such as that from a parabolic reflector

For a typical "pancake" beam, a flat disc-shaped radiation pattern

Using these relations, we can plot the gain -vs- far-field distance for these representative beam shapes:



1. Johnson, R., "Antenna Engineering Handbook," pg. 1-11.

From the above, we can see that:

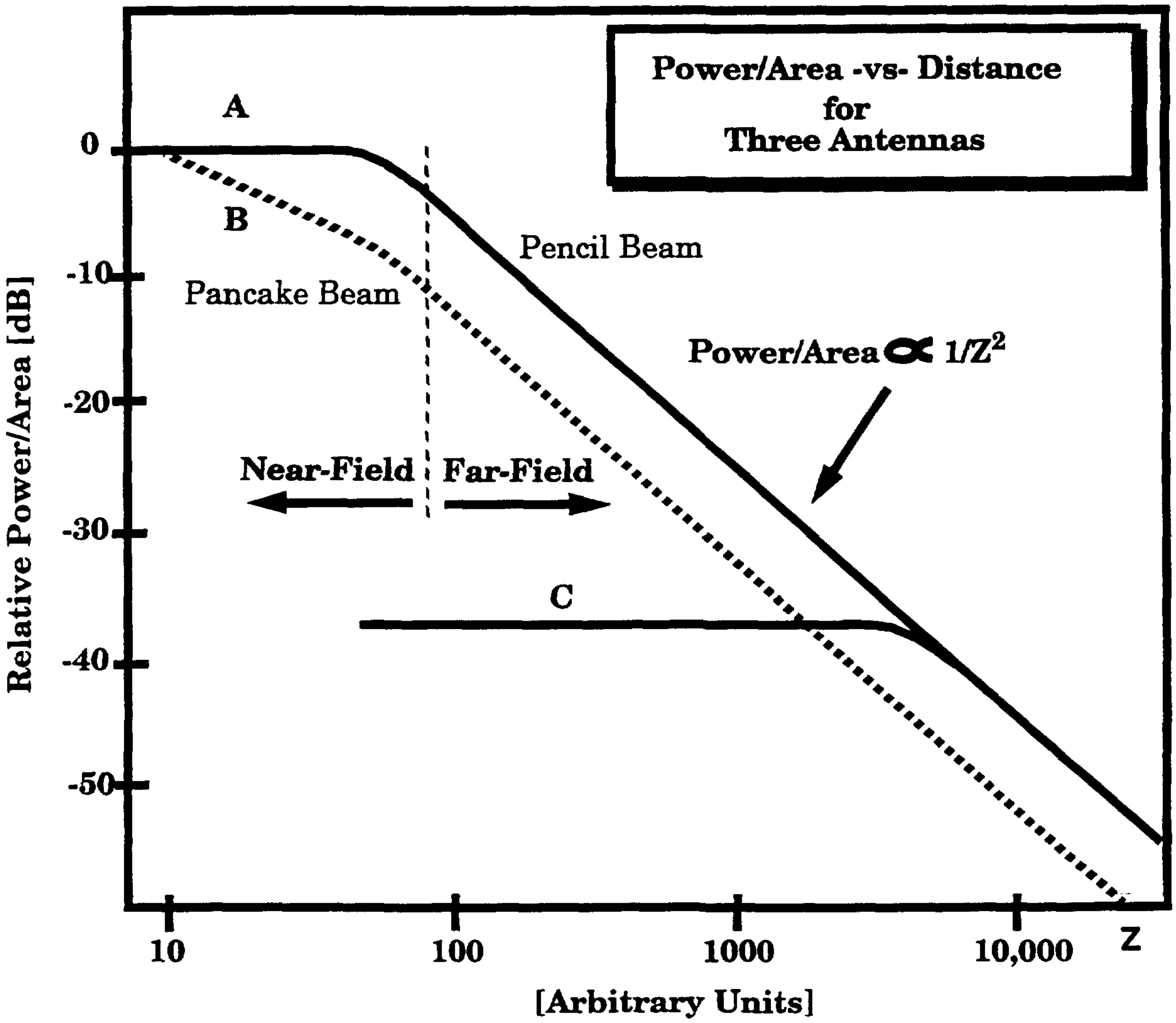
A. Depending on frequency of operation and details of design, far-field distances may be less than 3 meters, equal to 3 meters, or greater than 3 meters for practical mmWave antennas.

B. Antenna gain, hence EIRP, can differ widely between antennas of similar size. For example, a pencil beam antenna will have 17dB more gain - thus correspondingly higher EIRP - than a pancake beam antenna of similar dimensions .

Therefore, if 3 meters were to be chosen as the standard measurement distance, we would need to know the antenna gain and/or its pattern in order to deduce important power limits from our measurements.

Why Does It Matter?

If we want to observe the worst-case power density, for purposes of safety compliance, we need to know the power in the near field, preferably as close as possible to the radiator. If, on the other hand, we want to know the Effective Isotropically Radiated Power [EIRP], for purposes of estimating transmitter range, we need to measure in the far field.



From the above plot, we see that Antennas A and B have similar far-field distances, with the pancake beam, B, having less EIRP, hence less range. However, because the near-field behavior of A and B is entirely different, we see that these two antennas, which have different EIRPs, have similar power densities close to the antenna. Nothing can be inferred about this close-in power density from a far-field measurement without additional information about the antenna pattern.

On the other hand, when measured at very great distances, antennas A and C - both pencil-beam radiators - have equal power densities, hence their EIRPs are identical. But a measurement made at Z=1000, for instance - in the far field of A and the near field of B - would show very different power densities, and might lead to the conclusion that the higher-gain antenna C would have less range than antenna A, which is not the case.

Therefore, it is really necessary to know something about the beam pattern of mmWave antennas if proper conclusions are to be drawn from power measurements

Waveguide Bands

Some important standard waveguide bands for the frequencies of interest are:

Table 1: Waveguide Bands

Set "A"

Designation	Frequency
Q	33-50 GHz
U	40-60 GHz
V	50-75 GHz
E	60-90 GHz
W	75-110 GHz
F	90-140 GHz
D	110-170 GHz
G	140-220 GHz

Set "B"

Most measurement equipment will couple to free space through standard hardware available for these bands. However, not all equipment is available in all these bands [see below]. Note that the frequencies of interest [40 - 170 GHz] can most efficiently be covered with 4 waveguide bands - either Set "A" or Set "B". Many instruments make use of a set of interchangeable sensors, one for each available waveguide band. Until such time as services are implemented in the higher mmWave frequencies, measurements to 110 GHz would be sufficient, in which case only three waveguide bands [Q, V, W] would be necessary.

Power Measuring Equipment

Following is a list of some commercially available measurement equipment for the mmWave bands above 40 GHz. This list is provided for information only - no recommendations are implied.

A. For basic power measurements in free space, a broadband acousto-optic power meter has been used by plasma researchers and other laboratory workers. This technique has the advantage of freedom from frequency-dependent coupling to the wave under test throughout the mmWave spectrum, but does require a 40 Hz beam chopper to operate. Such meters are accepted as measurement standards in the U.K., and are commercially available.[2] Sensitivity is of the order of -30dBm.

B. For waveguide-band power measurements with greatest convenience, but less accuracy, power meters are available in standard waveguide bands, but only to 140 GHz.[3] Sensitivity is of the order of -30 dBm. All power meter measurements, of course, contain an element of error due to the uncertainty as to how much power is actually coupled into the sensing element.

C. Waveguide band detectors are available for use with video detection instruments, such as meters, scalar network analyzers, and antenna pattern measurement systems.[4] Sensitivity is on the order of -53 to -36 dBm.

D. For frequency-selective measurements, broadband RF spectrum analyzers are available to 50 GHz, and should be very useful for the lower frequency bands.[5] However, frequency-dependent reflections from the instrument, when combined with various input coupling arrangements [horns, adaptors, etc.] can introduce calibration errors.

E. Because equipment to be type-certified will be narrowband, and because free-space coupling tends to be through standard waveguide hardware, most frequency-selective measurements can conveniently be made with waveguide band harmonic mixers interfaced to a spectrum analyzer.[6] This is the recommended method for general and out-of-band spurious response testing. However, these spectrum analyzers are not preselected, so measurements require careful interpretation.[7] Sensitivities vary with waveguide band, from -104 dBm to -60 dBm [170 GHz].

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2. Thos. Keating Ltd., Billinghurst, West Sussex, England. [PC-based Power Meter for Far-Infrared and mmWaves].
3. Anritsu MP715A, MP716A, MP717A, MP81B, MP82B.
4. Millitech DXW series detectors.
5. Hewlett Packard HP8565E.
6. Tektronix WM780 series or Hewlett Packard 11970 series harmonic mixers operate with commercial spectrum analyzers and are available from 40 GHz to 170 GHz. Millitech MXW series mixers offer greater sensitivity but less convenience for measurements above 75 GHz.
7. Preselected downconverting mixers are available only to 75 GHz [HP 11974 series].

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